Quenched staggered light hadron spectroscopy from $48^3 \times 64$ at $\beta = 6.5$*

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We report our light hadron mass calculation based on an increased statistics of 250 quenched gauge configurations on a $48^3 \times 64$ lattice at $\beta = 6.5$. Quark propagators are calculated for each of these configurations with staggered wall source and point sink at quark mass values of $m_q = 0.01, 0.005, 0.0025$ and 0.00125. We also did additional calculations to improve our understanding of systematic biases arising from autocorrelation, source size, and propagator calculations. Our earlier conclusions that the flavor symmetry breaking is reduced and the ratio $m_N/m_\rho(\sim 1.25(4))$ is small remains robust.

Understanding low energy properties of the strong interaction from first principles of quantum field theory is one of the main goals for the lattice quantum chromodynamics (QCD). Hadron spectrum is a typical example of such low-energy phenomena and precision determination of hadron spectrum can serve as a validity check of lattice QCD [1].

Over the past few years, we have been calculating light hadron masses using quenched approximation to lattice QCD on a large lattice volume ($48^3 \times 64$) with small lattice spacing (coupling constant of $\beta = 6.5$) and small quark mass ($m_q = 0.01, 0.005, 0.0025$ and 0.00125) [2]. There have been numerous efforts (see for example [1,3]) for quenched light hadron spectrum calculation, most of which required extrapolations with respect to lattice volume, lattice spacing, and quark mass to approach large physical hadron size, continuum limit and light up and down quark mass. Controlling uncertainties arising from such extrapolations is difficult. In particular, extrapolations with regard to quark mass can be troublesome due to the fact that the chiral behavior of quenched theory is different from that of full theory [4].

We try to reduce various systematic errors associated with the extrapolations by calculating on a large lattice volume, small lattice spacing and small quark mass. Previous studies suggest that for quenched staggered spectrum, $\beta = 6.5$ lies in asymptotic scaling region. Thus the question lies on whether we can simulate large lattice volume at $\beta = 6.5$ and can reduce quark mass.

We use a combination of Metropolis and overrelaxation sweeps for generating quenched gauge field configuration. As we noted last year, we increased the sweep separation between measurement from 1000 to 2000 sweeps. This was necessary for the lightest quark mass value of $m_q a = 0.00125$ to be free of autocorrelation, but not for the three heavier mass values. For hadron spectrum calculation, staggered quark wall source with $m_q = 0.01, 0.005, 0.0025$ and 0.00125 and point sink is used. For Dirac matrix inversion, standard conjugate gradient (CG) method is used. This year we tested the numerical robustness of hadron propagators by comparing output from a stricter (machine-accuracy) convergence condition. We found no significant difference.

Table 1 summarizes our results. The quoted errors are from χ^2 fit. The corresponding jackknife errors are in agreement within 10 to 20 %. We measured nucleon masses from “corner wall” source and from “even point wall” source. However since “corner wall” nucleon effective mass does not show noticeable plateau, we present nu-

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cleon mass from "even point wall" source. The Goldstone pion mass (π) and non-Goldstone pion mass (π_2) agree within their errors for all the four quark mass values. So do the two different rho mesons, ρ and ρ_2 obtained as parity partners of b_1 and a_1 respectively. The flavor symmetry breaking in these channels is still not detectable despite the refined errors. In other words, our conclusion last year that the flavor symmetry breaking is not seen at $\beta = 6.5$ is robust and has been refined. The smaller errors are obtained partly because of the increased statistics: the wiggling of pion effective mass also reported last year has been reduced. In addition we have better control in selecting plateaus in the effective mass plot. This became possible through our source size study (see Figure 1). We clearly observe

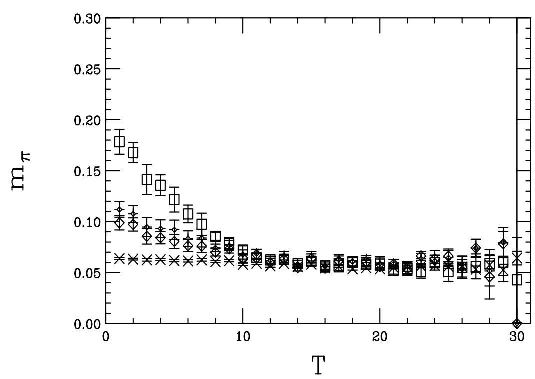

Figure 1. Nambu-Goldstone pion effective mass at $\beta = 6.5$ on $48^3 \times 64$ lattice for $m_q = 0.00125$. Three new different sizes for corner-wall, 12^3 ($\Box$), 24^3 ($+$), 36^3 ($\Diamond$) are used in addition to the $48^3(\times)$.

that the effective mass for all the four source sizes eventually approach a common plateau. The unwanted contribution from the excited states to the effective mass in earlier time decreases as the source size is increased. Wall size dependence for $m_q = 0.01$ pion effective mass is qualitatively the same. This behavior gives us a clear indication of how to define a plateau and results in smaller and more reliable error estimate. Since the combination $m_\pi L$ takes the values of about 2.9, 3.8, 5.3, and 7.6 respectively for quark mass $m_q a = 0.01, 0.005, 0.0025$ and 0.00125, we do not have to worry much about finite-volume effect on the current lattice with $L = 48$ either.

Figure 2 shows our Edinburgh plot. Without

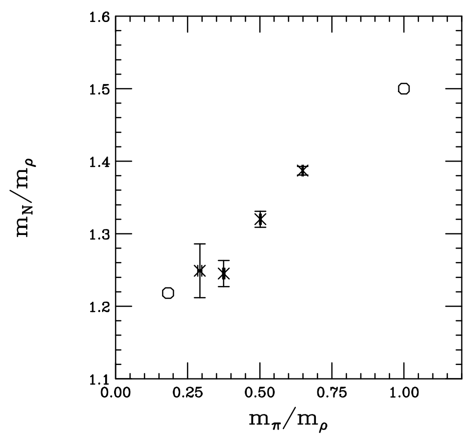

Figure 2. Edinburgh plot at $\beta = 6.5$ for quark mass $m_q = 0.01$, 0.005, 0.0025 and 0.00125. Nucleon masses from even-point wall source are used for m_N/m_ρ at each quark mass values.

any extrapolation with respect to quark mass, m_N/m_ρ approaches experimental value when the lattice volume is large enough to admit light pion.

Let us look for quenched chiral logarithm in our light hadron spectrum. In Figure 3, we plot m_π^2/m_q as a function of m_{π_2}. Instead of staying flat, the data points seem to be rising, similarly to what has been observed previously. This could be a finite volume effect as suggested in ref. [5]. Therefore, in Figure 4, we plot m_π^2 as a function of m_q. The two curves are results

Table 1
hadron masses for $m_q a = 0.01, 0.005, 0.0025$ and 0.00125

particle	$m_q a = 0.01$	$m_q a = 0.005$	$m_q a = 0.0025$	$m_q a = 0.00125$
π	0.1576(3)	0.1114(3)	0.0811(6)	0.0610(7)
π_2	0.1570(5)	0.1125(6)	0.0836(10)	0.0637(20)
σ	0.321(3)	0.320(6)	0.340(10)	0.291(10)
ρ	0.2430(7)	0.222(1)	0.216(2)	0.209(4)
ρ_2	0.2412(7)	0.221(1)	0.216(2)	0.212(3)
a_1	0.346(3)	0.326(4)	0.330(4)	0.311(5)
b_1	0.344(4)	0.326(6)	0.333(8)	0.349(16)
N	0.337(1)	0.293(2)	0.269(3)	0.261(6)
Δ	0.397(3)	0.382(3)	0.368(5)	0.360(7)

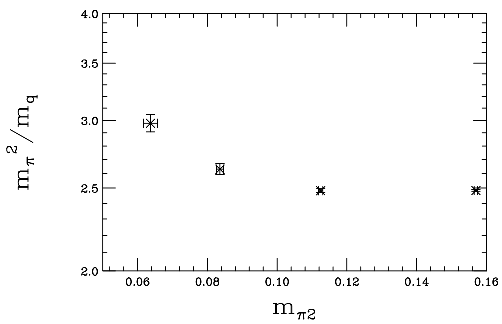

Figure 3. m_π^2/m_q(vertical axis, logarithmic scale) at $\beta = 6.5$ as a function of m_{π_2}(horizontal axis).

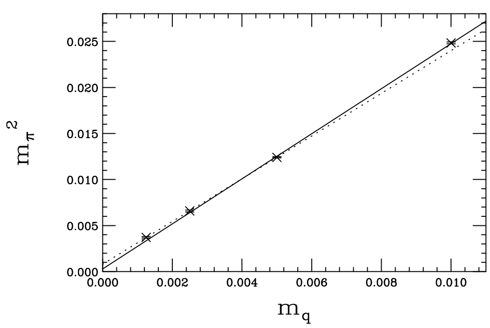

Figure 4. m_π^2 (vertical axis) at $\beta = 6.5$ as a function of quark mass (horizontal axis) The lines are results from fitting to a form, $m_\pi^2 = c_0 + c_1 m_q$ with three data points only.

from fitting to $m_\pi^2 = c_0 + c_1 m_q$ following suggestions by [5]. The broken line is fitted result using $m_q = 0.01, 0.005$ and 0.0025 with $\chi^2/d.o.f \sim 6.7$. The dotted line is fitted result using $m_q = 0.005, 0.0025$ and 0.00125 $\chi^2/d.o.f \sim 15.4$. Both lines show non-zero intercepts $(0.30(11) \times 10^{-2}$ for $m_q = 0.01, 0.005, 0.0025$ and $0.80(10) \times 10^{-2}$ for $m_q = 0.005, 0.0025, 0.00125$. However, the slopes change noticeably from 2.45(2) for $m_q = 0.01, 0.005, 0.0025$ to 2.32(3) for $m_q = 0.005, 0.0025, 0.00125$. Since our pion mass is already small for $m_q = 0.01$, we think that the change in slope is less likely due to the neglected higher order terms, $\mathcal{O}(m_\pi^n)(n > 2)$. Thus, our data does not appear to agree with a finite volume cutoff plus linear term picture of the pion mass.

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